

PAPER • OPEN ACCESS

The methodology of MMF calculation in magnetic circuit of induction motor by “ANSYS Maxwell”

To cite this article: O V Tikhonova *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **950** 012032

View the [article online](#) for updates and enhancements.



The Electrochemical Society
Advancing solid state & electrochemical science & technology
2021 Virtual Education

Fundamentals of Electrochemistry:
Basic Theory and Kinetic Methods
Instructed by: **Dr. James Noël**
Sun, Sept 19 & Mon, Sept 20 at 12h–15h ET

Register early and save!



The methodology of MMF calculation in magnetic circuit of induction motor by “ANSYS Maxwell”

O V Tikhonova, D D Mineeva, A T Plastun

Ural Power Engineering Institute, Ural Federal University, Yekaterinburg, Russian Federation

E-mail: olga_tikhonova_91@mail.ru

Abstract. In the paper the methodology of MMF calculation in magnetic circuit of induction motor by “ANSYS Maxwell” is considered. The calculation is based on the use of the total current law. The magnetic circuit of the induction motor is divided into several sections: stator tooth, rotor tooth, air gap, stator yoke and rotor yoke. Each section of the circuit is analyzed separately. The calculation result obtained using “ANSYS Maxwell” is compared with the results of the classical methodology.

Key words: induction motor, MMF, magnetic calculation, ANSYS Maxwell.

1. Introduction

A magnetic circuit calculation is one of main stages in an electromagnetic calculation of an electrical machine. In this stage a developer determines the value of the magnetizing force, which is needed to create a magnetic flux in an air gap of an electrical machine to induce electromotive force (EMF) of a given value [1].

Also this calculation makes it possible to determine the value of the saturation coefficient of the stator and rotor steel; consequently it determines whether the geometric dimensions of the magnetic core of the electric machine are selected correctly. Generally developers determines those parameters of induction motors using standard calculation methods from benefits by I Kopylov and P Sergeev [2]. Such “ANSYS Maxwell” program can be used to optimize this calculation and simplify engineering tasks.

In this work, the calculation of the magnetic circuit of a classic induction motor is made in two ways. The first one is using the classical calculation method [2] and the second one is using the application of “ANSYS Maxwell”. The results of the research are compared with each other in order to verify the correctness of the definition of a particular value with “ANSYS Maxwell”.

Using the concept of "the magnetic field tension" and the law of total current, this expression establishes the relationship between the magnetic flux and magnetomotive force (MMF) acting in this circuit and its geometric dimensions. This expression can be obtained for any part of the magnetic circuit.

The law of the total current states that the line integral of some closed loop is the product of the magnetic field strength and the selected loop length and in other side is the total current flowing through the section bounded by this loop [3].

Mathematically,

$$\oint H dl = \oint H \cdot \cos \alpha \cdot dl = I \cdot W \quad (1)$$

where H is the magnetic field tension, A/m; l is the magnetic line length, m; I is the current value, A; W is the number of wires in the loop.

The voltage drop between the points “a” and “b” of the magnetic circuit is equal the line integral of the magnetic field strength between these points [3]:



$$U_{m\ a-b} = \int \vec{H} \cdot d\vec{l}$$

(2)

The product of the electric current value and the number of wires is magnetomotive force (MMF):

$$F = I \cdot W$$

(3)

Using the above concepts, we can present the expression (2) in a form that is similar to the second Kirchhoff's law for electrical circuits.

$$\sum_{k=1}^p U_{mk} = \sum_{k=1}^n \pm F_k$$

(4)

Thus, the sum of voltage drops along the closed loop of the magnetic circuit is equal to the algebraic sum of MMF of coils in the loop.

2. The calculation stages

2.1. The magnetic tensors calculation in sections of the magnetic circuit by "ANSYS Maxwell"

The AO2-32-6 engine with a power of $P = 2.2$ kW, a voltage of $U = 220/380$ V, and a rotation speed of $n = 1000$ rpm was taken as the test machine [6].

The calculated engine model is shown in figure 1.

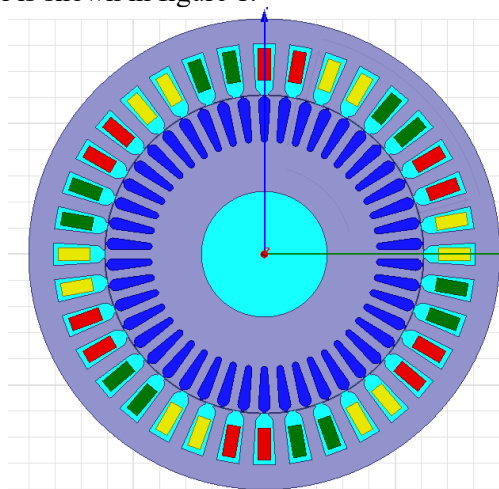


Figure1. The calculated AO2-32-6 engine model

Further it is necessary to select a closed integration loop (see figure 3). To find the integral over a closed line it is possible to divide this line into separate sections, along whose MMF is determined by the formula (2). Selected integration areas should be located along the magnetic lines. So it is necessary to provide a picture of magnetic field lines of the researched induction motor (see figure 2).

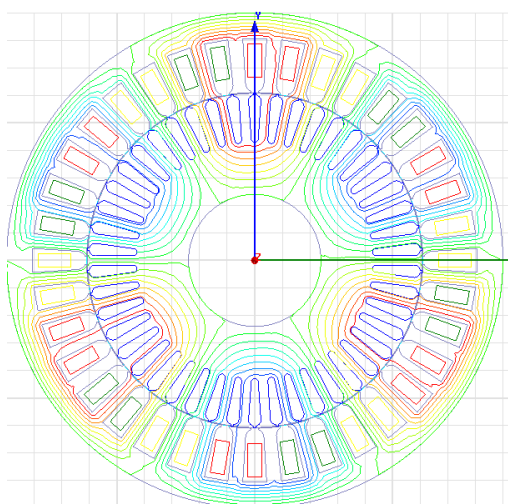


Figure 2. Magnetic field lines of the researched induction motor AO2-32-6

In figure 2 there is the picture of the distribution of the magnetic field for each pole. You can see that it is the same; therefore, the calculation can be performed on one pair of poles. As in the classical technique, the magnetic circuit is divided into several sections. They are a stator tooth h_{z1} , an air gap δ , a stator yoke L_{a1} , a rotor tooth h_{z2} and a rotor yoke L_{a2} .

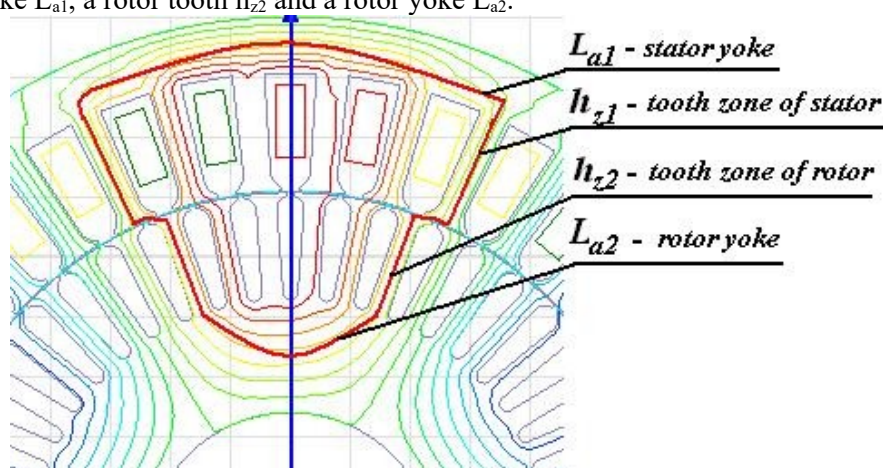


Figure 3. Lines for determining of the voltage of the magnetic circuit of the researched induction motor AO2-32-6

Closing in the magnetic circuit, the magnetic flux passes through the air gap and the tooth layers of the stator and rotor twice. A line is drawn along each section to determine the magnetic tension through integration (see figure 3).

The stator and rotor cores of the motor are made of laminated steel 2212.

The magnetic voltages are determined by the formula (2) using the calculator built into the program.

The current value is $I = 9.3$ A, the number of wires in the stator coil is $W = 47$. As is known, it is necessary to know the value of the tension H and the length of the integration line L to calculate the voltage. The value of the tension is taken according to the magnetization curve $B = f(H)$ for steel 2212, the length of the magnetic line according to the geometry of the magnetic circuit. The values of MMF for the sections of the circuit, the length of the lines of integration are shown in Table 1.

Table 1. The values of magnetic circuit MMF calculated by “ANSYS Maxwell”

<i>The area name</i>	<i>The line designation</i>	<i>The line length, mm</i>	<i>The MMF value, A</i>
----------------------	-----------------------------	----------------------------	-------------------------

An air gap, l_δ (for one side)	δ	2x0,3	430
An stator tooth, h_{z1}	h_{z1}	19,6	36
An rotor tooth, h_{z2}	h_{z2}	18,25	51
A stator yoke, L_{a1}	L_{a1}	89,4	180
A rotor yoke, L_{a2}	L_{a2}	15,2	3,9

MMF of the magnetic circuit of an induction motor is equal to the sum of MMF values of all its sections:

$$F_\Sigma = F_\delta + 2 \cdot F_{z1} + 2 \cdot F_{z2} + F_{a1} + F_{a2} \quad (5)$$

According to the formula (3), the total value of MMF of the magnetic circuit is

$$F_{\Sigma1} = 430 + 2 \cdot 36 + 2 \cdot 51 + 180 + 3,9 = 788 \text{ A.}$$

The saturation coefficient of the magnetic circuit is the ratio of the total MMF of the magnetic circuit F_Σ to the total value of MMF of the magnetic circuit in the air gap F_δ .

$$k_{\mu1} = \frac{F_\Sigma}{F_\delta} = \frac{788}{430} = 1,83(6)$$

The program of “ANSYS Maxwell” [4] also make it possible to present zone patterns of the distribution of magnetic induction of an induction motor (see figure 4) and show the most saturated zones of the magnetic circuit using a color scale. As can be seen in the scale, blue corresponds to induction values close to zero, and red matches to maximum induction values close to two Tesla.

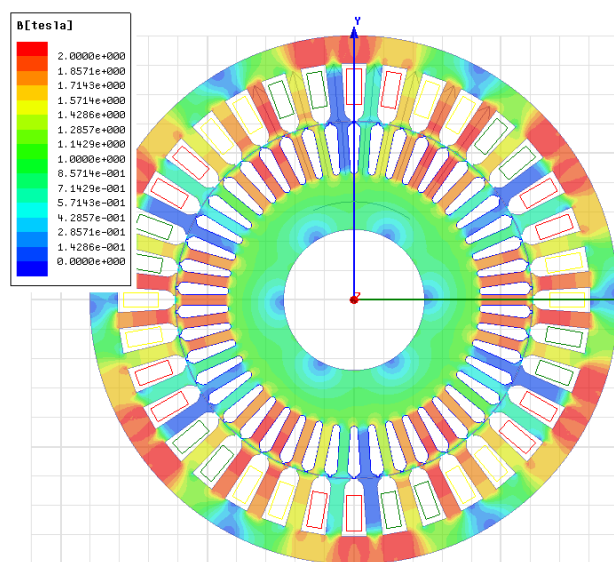


Figure 4. The zone pattern of distribution of the magnetic induction

Figure 4 shows that the most saturated areas are teeth and the stator yoke [5-6].

Based on the value of the saturation coefficient calculated according to the formula (6), the magnetic circuit of the induction motor is highly saturated.

2.2. The calculation of the voltages in the sections of the magnetic circuit using the methodology from the manual of I Kopylov

The following calculation was performed using the classical calculation methodology described in the manual by I Kopylov [2]. The calculation results are presented in Table 2.

Table 2. Values of the magnetic circuit MMF, calculated according to the methodology described in the manual by I Kopylov

<i>The area name</i>	<i>The line designation</i>	<i>The line length, mm</i>	<i>The MMF value, A</i>
An air gap, l_δ (for one side)	δ	2x0,3	417,4
An stator tooth, h_{z1}	h_{z1}	19,6	40,6
An rotor tooth, h_{z2}	h_{z2}	18,25	49,8
A stator yoke, L_{a1}	L_{a1}	89,4	179
A rotor yoke, L_{a2}	L_{a2}	15,2	3,9

The total value of MMF of the magnetic circuit was determined according to the formula (5), mathematically,

$$F_{\Sigma 2} = 417,4 + 2 \cdot 40,6 + 2 \cdot 49,8 + 179 + 3,9 = 781,1 \text{ A.}$$

The saturation coefficient of the magnetic circuit was determined by the formula (6):

$$k_{\mu 2} = \frac{781,1}{417,4} = 1,87.$$

2.3. Conclusions and the comparison of results

The study allows us to draw following conclusions and compare results:

- the total MMF value calculated using the application of “ANSYS Maxwell” is $F_{\Sigma 1} = 788 \text{ A}$ and $F_{\Sigma 2} = 781,1 \text{ A}$, the latest was determined according to the classical calculation methodology. The relative error in determining the total MMF by two methods is equal to

$$\Delta 1 = \frac{F_{\Sigma 1}}{F_{\Sigma 2}} = \frac{788}{781,1} \cdot 100 \% \approx 0,88 \% \quad (7)$$

- the relative error in determining the saturation coefficient of the magnetic circuit is

$$\Delta 2 = 1 - \frac{k_{\mu 1}}{k_{\mu 2}} = 1 - \frac{1,83}{1,87} \cdot 100 \% \approx 2,1 \%.$$

- thus, the difference in the results obtained by the two methods does not exceed 5%, from which it follows that the “ANSYS Maxwell” application software can be used to calculate the magnetic circuit of a classic induction motor.

References

- [1] Sergeev P, Vinogradov N 1950 Designing of electrical machines Moscow
- [2] Kopylov I 2001 Designing of electrical machines Moscow
- [3] Bessonov L 1964 Theoretical Foundations of Electrical Engineering Moscow
- [4] Tikhonova O Malygin I Plastun A 2017 Electromagnetic calculation for induction motors of various designs by “ANSYS Maxwell”*Int. Conf. ICIEAM*
- [5] Bal S Tumay Demirdelen T Tumay M 2019 Lightning Electric Field Analysis of a Transformer Using ANSYS Maxwell 3rd *Int. Simp. ISMIST*
- [6] Antik I 1938 Inductuion motors winding data Moscow